

COSMIC DISTANCE INDICATION OF THE NATURAL ENVIRONMENT

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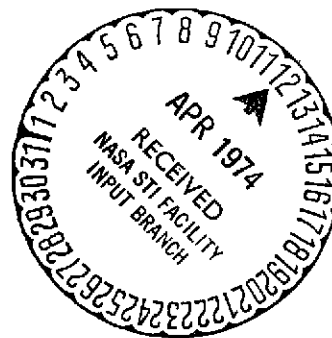
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16. Abstract This article on cosmic indication of the natural environment deals with the value of research carried out by spacecraft into the surface of the Earth. Since the advent of space flight, meteorological data have been obtained which are extremely reliable and timely. Natural formations can also be observed extremely well from space, and data resulting from observations can be used in ecology. Aerosol plays an important part in thermal conditions, and sounding of the atmosphere from space is already well developed.			
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COSMIC DISTANCE INDICATION OF THE NATURAL ENVIRONMENT

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The immense growth in the scale of man's economic activity /41* during the scientific-technical revolution requires the development of methods for a systematic check on the condition of the natural environment on a global scale. Naturally, the most adequate means of research into problems of planetary ecology is the use of artificial earth satellites and other space vehicles. The use of space technology also gives wide scope for an all-round study of natural resources, especially those of the world's oceans. The most convenient method for carrying out this work is the launching of automatic space satellites. However, a very wide range of tasks can effectively be solved only by using manned spacecraft, the crew of which consists of specialists, trained to carry out the necessary scientific program. Permanent orbital stations will be the most useful for carrying out long series of complex-continuous observations when studying the natural environment and natural resources. One of the main advantages of these stations is the possibility to carry out directly on-board logical analysis of the situation, to take decisions on selecting objects for observation during the most favorable conditions and use the equipment which, at the given moment, can give the most complete information on the phenomenon being investigated. When there is an engineer on board the station, breakdowns of instruments can quickly be repaired and, by the same token, they can be kept operating for long periods. Since replacement crews are available, materials for the experiment (photographic film, etc.) can be delivered from the station to Earth in sections -- for analysis of the data obtained and, if necessary, subsequent program correction. Experiments of space flights carried out in the USSR completely confirmed these expectations, which are used for

*Numbers in the margin indicate pagination in the foreign text.

scientific research of manned orbital stations.

It must be emphasized that the richest sources of information are visual observations by cosmonauts [1]. The pioneer space flight by Yu.A. Gagarin was important, not only from the point of view of testing a spacecraft and giving an answer to the question, can a man stay in space, but also for the first, visual sightings of our planet from near-Earth orbit. Further successes in rocket-space technology are linked with the gradual increase of duration of flights and the saturation of scientific experiments. New horizons were opened in this field when the "Salyut," the first manned orbital scientific station in the world, was launched. The most significant in volume and diverse in possibility is the interpretation of material of natural formations photographed from space, and also television and infrared photography. Space meteorology is the most convincing example of the efficiency of space photography. /42

Soviet and American meteorological satellites carry out daily space patrols of the weather. Television and infrared equipment in them make it possible to obtain, day and night, images of the Earth, with which one can study the peculiarities on the distribution of cloud cover over our planet. Synchronous satellites, sent in equatorial orbit at a height of approximately 37,000 km (in this case, the period in which the satellite rotates around the Earth in 24 hours, and, as it were "hangs" over a specific point of the equator), help to trace constantly the dynamics of cloud cover in tropic and subtropic zones. The use of satellite meteorological information has made for a more reliable and timely weather-forecasting service.

Actinometric instruments for measuring the solar radiation back-scattered by the Earth into the cosmos and natural thermal radiation of the Earth in cosmic space are part of the set of

scientific equipment in Soviet meteorological satellites of the "Meteor" system. On the basis of these measurements are studied the laws governing planetary distribution of the "arrival-expenditure" of heat, that is the energy of our planet and, it must be said, that research in the past few years has brought about significant corrections to data already at hand. Thus, measurement of solar radiation from high-altitude balloons, begun by workers at the Leningrad University in 1961, led to the conclusion that there was a marked overstatement of the value of the solar constant accepted earlier ($2 \text{ cal/m}^2 \cdot \text{min}$) which characterizes the amount of radiant energy of the Sun, which reaches the external limit of the atmosphere when the Earth is at its average distance from the Sun. It appeared that the maximum value of solar constant does not exceed $1.94 \text{ cal/m}^2 \cdot \text{min}$ (this result has been confirmed in a whole series of American research). Furthermore, it was ascertained that, depending on the activity of the Sun, the constant can be reduced by 2-2.5%, in comparison with its maximum value. At first glance, these would appear to be facts of little importance; in actual fact, they are very significant. As theoretical calculations show, the change of value of the solar constant by 1% must cause a change (in the same direction) of the average temperature of the atmosphere by approximately 1%. If one takes into account that the much-discussed subject of the warming-up of the climate (especially in the Arctic) in the first half of the 20th century, was expressed in a growth of average value of temperature by tenths of a fraction of a degree, the meaning of the results referred to becomes clear. This research undoubtedly must be continued by the active use of modern technical means for observation.

Satellite data show that there is a significant overstatement of the values of albedo (the reflective power) of the Earth, obtained earlier by theoretical calculations (this is especially so of low latitudes). Using these calculations to determine the

arrival-expenditure of heat, we significantly underestimated the value of solar radiation absorbed by the Earth. Detailed analysis showed that the "excess," in comparison with the given calculation, radiation is absorbed mainly by the oceans. High-accuracy measurement of the planetary arrival-expenditure of heat now /43 takes on a more important meaning, since man's economic activity has a greater effect on the Earth's energy balance.

The results of using numerical methods for weather forecasting by using computers, that is the forecasting of atmospheric pressure, wind direction and speed, temperature of the air, precipitation and other parameters based on accurate hydrodynamic and thermodynamic equations, describing atmospheric processes, to a great extent, depends on the availability of data on the initial values of the indicated (but not always taken together) parameters. Therefore, now great attention is being paid to the development of methods for obtaining quantitative, meteorological information by using satellites. In essence, we are talking of a new stage of development of satellite meteorology, which is characterized by the transition to satisfy the practical requirements of numerical methods of weather forecasting in appropriate initial information.

By recording the radiation of the Earth on different wavelengths from satellites (the so-called outgoing radiation), one can obtain, for example, information on the vertical profiles of temperature and moisture in the air. This is more conveniently done by measurement data of the infrared thermal radiation of the atmosphere. This radiation, as part of a multi-component gaseous medium, has a very complex relationship to the wavelength. Where the atmosphere is almost transparent ("transparency windows"), the satellite records mainly radiation of the Earth surface and, consequently, those data which make it possible to determine temperature of the Earth surface. But where the atmosphere is

a strong absorber of radiation, the basic contributions to the outgoing radiation are made by the external layers of atmosphere, and the value of radiation characterizes their temperature. In this way, by recording the outgoing radiation on different wavelengths, one can "stratify" the atmosphere and determine the vertical profile of temperature.

The practicability of thermal sounding of the atmosphere from satellites, however, is by no means simple, since this problem belongs to the class of noncorrect ones, which have no single-valued solution. Efforts by several groups of scientists in the USSR and USA have practically managed to overcome the mathematical difficulties by using various regularizing methods. The problem of high-accuracy measurement of infrared outgoing radiation was also solved successfully.

It is known that there is a complication when using data measurement of infrared outgoing radiation to determine the vertical temperature profile making it necessary to take into account the effect of cloud. Since dense clouds are opaque to this radiation, it is impossible to sound the sub-cloud layer. Therefore, measurement of the microwave (centimeter band) of the outgoing radiation has more possibilities. Research by workers of the Institute of Physics of the Atmosphere and Institute of Radio Engineering and Electronics of the Academy of Sciences of the USSR, carried out according to data of these measurements, which were first recorded on the "Kosmos-243" satellite, showed the possibility for the successful solution of such tasks as determining the general content of vaporous and liquid moisture in the atmosphere, fixing the position of the boundary of ice cover and others.

The development of satellite meteorology has prepared the basis for further wide introduction of methods of remote cosmic indication into investigation of the natural environment and

natural resources. Although now, cosmic ecology uses for this purpose space photography material, use is already being found for methods of multispectral photography (obtaining pictures of the Earth in several sections of the spectrum). In the table are shown examples, when interpretation of pictures obtained in this way is always possible (1), usually possible (2), sometimes possible (3) and impossible (4).

TABLE.

Characteristic Sought	Section of Spectrum (μm)			
	Color Infrared 0.51-0.89	Green- blue 0.47-0.61	Red Infrared 0.68-0.89	Yellow- Green 0.59-0.715
Type of vegetation	3	4	4	3
Phase of vegetative stage	1	4	2	4
Pasture	2	2	3	2
Sand	1	1	2	1
Exposed rocks	1	1	2	1
Rivers and fresh reservoirs	1	2	2	3
Dried-up riverbed	1	3	2	3
Lake	1	2	2	2
Town	3	3	4	3
Buildings	4	4	4	4
Mines	4	4	4	4
Highways and railroads	1	2	2	1
Composition of road surface	4	4	4	4

Examples from the table are of individual illustrations: the actual possibilities of interpretation are much wider. Interpretation of the pictures, as a rule, is qualitative. It is obvious that processing of quantitative methods must only be carried out by using quantitative characteristics which, in the example given, can serve as brightness fields in various ranges of the spectrum. Therefore, the most promising are methods for obtaining multispectral images by multichannel long-range photometers (or radiometers), which give, not only a "picture" of the Earth's surface, but also the brightness field in absolute units.

Much interest in the program of sounding the atmosphere from the cosmos is being paid to determining the vertical profile of the concentration of aerosol (dust particles) contained in it. This research has, above all, important meteorological aspects. It is known, for example, that pollution of the atmosphere after volcanic eruptions always led to a considerable reduction of solar radiation arriving on the Earth's surface and a noticeable change of thermal conditions in the atmosphere. Industrial pollution causes the same effects. Systematic aerosol sounding from space was carried out from Soviet manned spacecraft. This research was begun when the twilight aureole was photographed (V.V. Nikolayeva-Tereshkova, K.P. Feoktistov). Later, its spectra were obtained for the first time (B.V. Volynov, Ye.V. Khrunov). Interpretation of all this material gave important new information on atmospheric optics and the space distribution of aerosol.

Remote sounding also embraces a large number of questions dealing with the study of various characteristics of the Earth's atmosphere, and also surface layers of the ground and seas. The main aim of the work here is research into natural formations and structures with recorded data of spectrum reflection. The /45 first example for solving this type of problem was a joint experiment carried out during a formation flight of "Soyuz-6, 7 and 8" spacecraft, when photographs were obtained of spectra of various natural formations from the cosmos, and also a number of optical measurements were carried out on Earth by two aircraft-laboratories at different heights. This research was continued during the flight of "Soyuz-9." It showed that the presence of complex optical data makes it possible to carry out extremely accurate differentiation of natural formations. Here, the solution of the problem of selection of the optimum set of data which would allow sufficient reliable characteristics of the natural formations undergoing research was a very important factor.

Analysis of the information content of material obtained shows that in order to identify natural formations by their reflection spectra, there is no need to record the spectra completely; it is sufficient to have the values of coefficients of spectral brightness for several wavelengths.

These complex subsatellite geophysical experiments, which were the first to be carried out in the world, are extremely important for developing cosmic ecology which, in the near future, must be used to work out reliable methods for interpreting remote indication material [2]. Complex data are also necessary to determine the so-called transfer function of the atmosphere, information about which is required so as to eliminate its effect on the atmosphere when recording spectra of natural formations from space.

Recently, much importance has been given to the development of methods for the remote determination of soil characteristics (especially moisture and temperature). Measurement data of microwave radiation are successfully being used for this project. Here, the most promising is the interpretation of results of measurement of polarization of shortwave back-scattered radiation from the ground on a wavelength of approximately $0.5 \mu\text{m}$. Polarization of reflected sunlight increases with the rise in moisture in the soil (when there is saturant moistening, light reflected at the Brewster angle is completely polarized), especially where there are wide angles of reflection. Here, it is important that measurement of the polarization has little dependence on the angle of incidence of solar radiation. A sufficiently reliable solution of this problem, however, is only possible when there is preliminary identification of soil type, since conditions of polarization when light is reflected by different soils are specific.

Since there is a requirement to increase the production of food products, more attention is being paid to biological resources of the world's oceans. Since its biological production is determined by the photosynthesis process, remote methods for tracing the space distribution and dynamics of photosynthesis activity must be developed. Chlorophyll is the key indicator to biological productivity in the ocean. Measurement of its content and variations are characterized by the intensity of photosynthesis and the conditions for biomass production. At the same time, the speed of these processes depends on the presence of such nutrient components as nitrogen and phosphorus. Contaminating components have a great influence on photosynthesis activity. Thus, the presence of mercury at a concentration of 10^{-9} slows down photosynthetic activity by 50%. The concentration of DDT, equal to 10^{-8} , also suppresses photosynthesis to a considerable extent. Consequently, measurement of chlorophyll makes it possible to judge both the biomass content (phytoplankton) and the associated factors (concentration of nutrient substances and pollution).

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Since data are available which show that the chlorophyll content correlates with the temperature of the ocean's surface, interest is being shown in the simultaneous remote measurement of both of these parameters. Such measurement is also important from the point of view of using it for the characteristics of upwelling (the rise of deep, cold water to the surface), the demarcation of zones of marine currents and water of various origins.

Remote measurement of chlorophyll can only be done through transparency windows in the atmosphere and the visible range of the spectrum, since only in this wavelength band, radiation strikes the water to a sufficient depth (up to 150 m). Preliminary development showed that by measuring the difference

(or ratio) of intensity of back-scattered radiation at wavelengths of 443 nm (maximum absorption) and 525 nm (comparison zone), can characteristics be obtained which are extremely sensitive to chlorophyll content.

On the basis of what has been said (although we did not deal, for example, with questions relating to geology, geobotany, geomorphology, etc.), the conclusion can be made that the most promising method for obtaining the necessary information for cosmic ecology is the combination of multispectral photography methods (especially by using multichannel scanning long-range photometers and radiometers) and spectrometry in the longwave band -- from the ultraviolet to the microwave range of the spectrum. Interest is being shown in the use of lidars (laser sounding). Since methods for remote cosmic indication are ambiguous, adequate methods of interpretation of measurement can only be developed by using the combined analysis of data of space vehicles, aircraft-laboratories and ground observation in specially selected areas. Here, it is most important to look into the most effective methods for processing the information obtained, which, in the future, will attain enormous proportions and require extremely high-speed computers.

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